Data from Rapid Inventories of Bats As Insight for Forest Habitat Management

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Abstract: The need to understand habitat requirements for bats is becoming more urgent as new risks pose unprecedented challenges to these unique mammals. We undertook a brief, intensive survey to investigate bat habitat use in and around the Apalachicola National Forest during May 2012. Making use of experienced volunteer biologists representing many agencies and organizations, we surveyed 31 sites during three nights of mist netting, capturing 245 bats of eight species. We used logistic regression and cluster analysis to evaluate habitat use and diet. Although data collected during such a brief period have limited power, trends suggest that vegetation characteristics at a small spatial scale surrounding capture sites (100-m radius) affected occurrence of bat species more than vegetation characteristics at a larger spatial scale (500-m radius), and that the type of anthropogenic roost structure at the capture site (e.g., bridge, culvert) was more influential than the type of water body (e.g., pond, creek). Assessment of bat guano revealed that Hemiptera (true bugs) were the dominant order of invertebrates consumed by bats; bats grouped into two categories based on whether the second most common order consumed was Lepidoptera (moths) or Coleoptera (beetles). Land managers in the Florida Panhandle should consider bats when planning forest management activities near water features in upland and disturbed habitats during maternity season; existing silvicultural Best Management Practices may not adequately address bat habitat needs. Also, water crossing structures should incorporate design features consistent with known roost preferences of local bat species. Lastly, we suggest that brief surveys performed by expert volunteers have the potential to contribute more than has historically been gleaned: with modest modifications, foundational data on habitat use and diet could be collected to inform forest management activities.

Key words: bats, diet, forest management, habitat use, inventory

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Recent evidence indicates the role bats play in such valuable ecosystem services such as controlling agricultural pests, seed dispersal, and pollination has been largely underappreciated (Kunz et al. 2011). Estimates of the devastating economic and environmental impacts resulting from the increased use of pesticides that would be needed if the biological control provided by bats was lost (Boyles et al. 2011) have increased realization of the essential ecological role of bats in the United States. Given the growing interest in the ecological importance of this taxon, now is an apt time for further investigation into their habitat needs in regions where they have been understudied. Knowledge of bat habitat use in Florida is surprisingly limited, despite the large increase in research efforts on bat habitat use elsewhere in the United States during the past 30 years (Kunz and Fenton 2003, Lacki et al. 2007).

The Florida Panhandle is a unique region for bats for a number of reasons. First, this area contains large, contiguous blocks of forested land, providing intact forest habitat conditions that are becoming increasingly rare in other parts of the state as human populations grow (Oetting et al. 2012). Second, North Florida has cave hibernacula (Gore et al. 2012) and is the southern-most extent of the distribution of several hibernating bat species, some of which are considered species of concern in the state (Marks and Marks 2006, FWC 2011). Third, during the spring of 2012, Florida was one of only three states bordering the Atlantic Ocean not yet affected by white-nose syndrome, an emerging infectious disease that first appeared in 2006 in New York and rapidly spread up and down the east coast, killing millions of hibernating bats in 16 northeastern states, but not yet South Carolina, Georgia, or Florida (http://www.fws.gov/northeast/white_nose.html.). Estimates suggest that nearly 6 million individuals in 25 states and five Canadian provinces have died since 2006 (USFWS 2014), with the mortality rate in infected hibernacula ranging from 30% to 99% annually (Frick et al. 2010). Thus, gaining information on bat habitat use in Florida during 2012 provided baseline data prior to the potential movement of this deadly disease into the state, and provided data from a healthy population of bats during a period when few such populations existed on the east coast.

Rapid biological inventories can provide valuable information to guide local, regional, and global conservation efforts (Stohlgren et al. 1994, Meese et al. 2003). Recognizing the importance of such efforts, the Southeastern Bat Diversity Network initiated an ongoing collaborative effort to sample bat communities across the southeastern United States. This event, called a Bat Blitz, has taken place annually since 2002, providing inventory data on state and federal lands throughout the region. These events provide a coordinated, intensive, short-duration survey across an extensive area using experienced volunteers to gain information on local bat populations. They unite bat experts willing to contribute time and equipment to help develop lists of local bat species, foster educational opportunities in the communities where they are held, and provide positive local media exposure for bat conservation. We suggest that these events have the potential to contribute more benefits than have historically been gleaned: with modest modifications, foundational data on habitat use and diet could also be collected to inform forest management activities.

Our overall goal was to gain information about bat habitat use and diet from data collected through means typically employed at Bat Blitzes and obtained during the 2012 Bat Blitz held in north Florida. Our specific objectives were to (1) determine which habitat characteristics played the greatest role in explaining variation among sites in the occurrence of each bat species, (2) characterize the diet of each species, and (3) determine if species could be grouped according to habitat use or diet such that managers could more easily develop plans that address species needs without resorting to an inefficient, single-species approach.

Methods

Data Collection

Survey sites were located in a region of the Florida Panhandle that stretched ~80 km east to west, and ~65 km north to south. This region encompassed parts of Calhoun, Leon, Liberty, and Wakulla counties. Vegetation communities consisted primarily of a mix of upland and wetland forests predominated by pine flatwoods, upland pine and sandhill, hardwood forested uplands, and freshwater forested wetlands (FNAI 2010). Within this region, ~150 potential survey sites were visited to assess suitability for bat mist netting during a six-month period prior to the actual surveys. Each of these potential survey sites was identified as a location suspected to be used by foraging bats: narrow ponds, creeks, and rivers where bats tend to congregate for feeding, or densely forested roads with an overhead canopy that could serve as bat travel corridors.

We surveyed 31 of these sites for bats over the course of three consecutive nights during late May 2012. Each site was surveyed for one night due to known declines in capture rates when netting is conducted at the same site on consecutive nights. Sites were located on federal, state, and private lands including Apalachicola National Forest, Joe Budd Wildlife Management Area, Torreya State Park, Wakulla Springs State Park, Apalachicola Bluffs and Ravines Preserve, and St. Marks National Wildlife Refuge. Late May was chosen because bat species in the region are pregnant or lactating at this time of year (Marks and Marks 2006).

Bats were captured using single-, double-, or triple-high mist net sets, with each net having dimensions of 2.6-m height × 6-, 9-, or 12-m length. Each net was opened shortly after sunset and remained open for four hours. Groups of 4–8 trained volunteers from ~30 agencies and organizations (state and federal agencies, private consulting companies, non-profit organizations, zoos, and universities) set and attended nets at each survey site. Species, sex, reproductive condition, age, weight, forearm length, and presence of wing tissue damage were recorded for each bat captured. Most bats were held individually in cloth bags for a period of time after processing to obtain guano samples, but released within one hour of initial capture. Guano that accumulated in each capture bag was collected and stored until analysis in a labeled plastic vial at –10 C. Capture and handling procedures followed guidelines from the American Society of Mammalogists (Sikes et al. 2011) and were approved by the Animal Research Committee of University of Florida.

Habitat Use Analysis

We analyzed the data to determine which ecological factors played the greatest role in explaining variation among sites in the occurrence of each species. We developed a series of *a priori* candidate models that could potentially explain the observed patterns, and then evaluated the relative strength of each using a model selection approach. We selected this approach because it (1) provides an objective means of determining which habitat characteristics best explain variation in bat occurrence, (2) provides a ranking and weighting of all candidate models so that the plausibility of each model under consideration can be compared, and (3) enables the calculation of relative variable importance, providing insight into the utility of each variable in explaining variation in each species occurrence (Johnson and Omland 2004).

We reasoned that bat occurrence would be motivated primarily by roosting opportunities and/or foraging opportunities, and that since wildlife consider multiple spatial scales when making habitat selection decisions, vegetation characteristics at either small or larger spatial scales might be relevant. Therefore, the factors we investigated were the type of anthropogenic roost structure present at the capture site (e.g., bridge, culvert, etc.), the type of water body at the capture site (e.g., swamp, creek, etc.), the dominant vegetation communities and the heterogeneity of vegetation communities at a small spatial scale (within a 100-m radius of the capture site) and at a larger spatial scale (within a 500-m radius of the capture site). Size of the larger spatial scale was selected based upon mean foraging area of the species of greatest conservation interest (*Corynorhinus rafinesquii*), reported in the published literature as equivalent to a circle with a radius of 500 m. The dominant vegetation communities and the heterogeneity of vegetation communities were determined using GIS data layers from the Florida Fish and Wildlife Conservation Commission (2003 landsat enhanced satellite imagery – 'FL-veg03').

To investigate variation among sites in occurrence of each species of bat we developed 20 models that contained one, two, or three of the explanatory variables described above (Table 1) and also included a null model (intercept only model) to evaluate the usefulness of all other models in predicting patterns of bat captures. The same candidate set of models was used for all bat species so that we had a balanced design, enabling accurate calculation of relative variable importance weights (Burnham and Anderson 2002). Highly correlated variables ($|r| > 0.5$) were never included in the same model. We included capture effort intensity (square meters of mist nets deployed) in all models to account for variation imposed by our sampling that may have confounded the true ecological patterns of interest. Lastly, we assessed the fit of selected models using Hosmer and Lemeshow goodness-of-fit tests and Cox and Snell pseudo R^2 (Hosmer and Lemeshow 2000). All data were modeled with binary logistic regression using Proc Logistic in SAS (2011).

We used model selection to rank candidate models according to their relative likelihood, using Akaike's Information Criteria corrected for small sample sizes (AICc; Burnham and Anderson 2002). For each species, we ordered all models according to the difference between the AICc score of each model and the lowest AICc score of all models for that species (DAICc; Burnham and Anderson 2002). We used Akaike weights, w_i, to evaluate the weight of evidence in favor of each model, and calculated relative variable importance by summing the weight for each model containing a particular variable and dividing by the number of candidate models in which that variable occurred. To account for model selection uncertainty, we used model averaging to calculate all reported parameter estimates, standard errors, and confidence intervals.

Table 1. Variables used to explain variation in bat captures among sites.

Variable code	Variable description	Variable values
WaterType	type of water body at capture site	*creek, pond, swamp, dry*
RoostType	type of anthropogenic roost at capture site	*concrete culvert, concrete bridge, other bridge* (wooden or metal), *none*
HabMaj100m	primary habitat type within 100m of capture site	*Disturbed* (bare soil/clearcut, crop field, high impact urban, low impact urban, shrub and brushland); *upland* (hardwood hammock forest, mixed pine-hardwood forest, pinelands, sandhill); *wetland* (bay swamp, bottomland hardwood forest, cypress swamp, freshwater marsh/wet prairie, hardwood swamp, mixed wetland forest, open water, shrub swamp)
HabHet100m	no. of habitat types within 100m of capture site	integer ranging from 1 to 10
HabMaj500m	primary habitat type within 500m of capture site	*Disturbed* (bare soil/clearcut, crop field, high impact urban, low impact urban, shrub and brushland); *upland* (hardwood hammock forest, mixed pine-hardwood forest, pinelands, sandhill); *wetland* (bay swamp, bottomland hardwood forest, cypress swamp, freshwater marsh/wet prairie, hardwood swamp, mixed wetland forest, open water, shrub swamp)
HabHet500m	no. of habitat types within 500m of capture site	integer ranging from 6 to 14
Survey intensity	no. of meters^2 of mist net	A positive value ranging from 62.4 to 210.6

Diet Analysis

All guano pellets collected from an individual bat were treated as a single sample. In the laboratory, we teased apart each guano sample in a Petri dish containing 95% ethyl alcohol. We identified invertebrate parts in pellets to Order using a dissecting microscope, comparing invertebrate fragments in guano pellets to reference mounts made of invertebrates collected nearby. Whole invertebrates were collected with a Universal Black Light Trap (Bioquip Inc., Rancho Dominguez, California) with a 12-watt fluorescent black light tube powered with a 12-volt battery and a "no-pest strip" (Hotshot, Newport Beach, California) in the bottom of the trap to function as a killing agent. We visually estimated the percentage of each guano sample composed of each invertebrate order (percent volume) and then calculated the mean percent volume for each order for all individuals of a given species of bat (Whittaker et al. 2009). We also calculated the frequency of occurrence of each order for each species of bat. Each sample was processed separately by two individuals and results were then averaged to increase accuracy.

We used cluster analysis to sort species of bats into groups according to similarities in diet. We applied an arcsine square-root transformation to the percent volume of each food item consumed by each species and computed a matrix of Euclidean distances for these data. We then conducted a cluster analysis using Ward's minimum variance method to produce a dendrogram reflecting the degree of similarity in food resource use among species (McCune and Grace 2002). Calculations were done using Proc Cluster in SAS (2011).

Results

We captured 245 bats during approximately 124 hours of mist netting, with an average of 8 bats captured per site. The maximum number of bats caught at a site was 57, and only 3 of the 31 sites sampled had zero captures.

Eight bat species were captured. The most widespread species (those caught at the greatest number of sites) were Seminole bat (*Lasiurus seminolus, 19 sites*), evening bat (*Nycticeius humeralis, 17 sites*), red bat (*L. borealis, 13 sites*), and Southeastern bat (*Myotis austroriparius, 13 sites*). The four remaining species were captured relatively infrequently: tricolored bat (*Perimyotis subflavus, 5 sites*), big brown bat (*Eptesicus fuscus, 4 sites*), Rafinesque's big-eared bat (*Corynorhinus rafinesquii, 4 sites*), and Brazilian free-tailed bat (*Tadarida brasiliensis, 1 site*).

Habitat Use

The Brazilian free-tailed bat was captured at only one location, so habitat use by this species was not analyzed statistically. For each of the other seven bat species, there was a high degree of model selection uncertainty. Of the 21 models investigated for each species, six received substantial support (ΔAICc $\leq$ 2.0) for the data pertaining to red bats and Southeastern bats, five models for Seminole bats, four models for big brown bats, three models for big-eared bats, two models for evening bats, and one model for tricolored bats (Table 2). The null model did not receive substantial support for any bat species, indicating that the explanatory variables we investigated were related to habitat use of these bats (e.g., low ΔAICc scores associated with null models would have suggested we had investigated variables with poor explanatory power or that activity levels of bats were too low to arrive at conclusive results). The fit of most models was adequate (as determined through goodness-of-fit tests and R^2 estimates), although some models for two species fit fairly poorly (red bats and Southeastern bats). Also, all final model-averaged parameter estimates had confidence intervals that overlapped zero, indicating our data had low power and therefore patterns identified here should be interpreted as trends

Table 2. Description of models receiving substantial support (ΔAICc ≤ 2.0) when fit using logistic regression to predict probability of occurrence of bat species in and near the Apalachicola National Forest, 2012. K = number of parameters, AICc = Akaike's information criteria corrected for small sample sizes, ΔAICc = the difference between the AICc score of each model and the lowest AICc score for that species, w_i = Akaiki weight, goodness of fit (X^2 with df values) determined by Hosmer and Lemeshow method.

Bat species[a]	Variables in model	K	ΔAICc	w_i	Goodness-of-fit	Cox and Snell R^2
CORA	WaterType, HabMaj500, HabHet500	6	0	0.35	$X^2_6 = 0.83, P = 0.99$	0.63
	WaterType, HabMaj100	5	1.06	0.21	$X^2_7 = 1.95, P = 0.96$	0.66
	WaterType, HabMaj100, HabHet100	6	1.60	0.16	$X^2_6 = 3.00, P = 0.81$	0.72
EPFU	RoostType, HabMaj100	5	0	0.27	$X^2_6 = 3.35, P = 0.76$	0.63
	RoostType, HabMaj100, HabHet100	6	0.55	0.20	$X^2_5 = 8.08, P = 0.15$	0.65
	HabMaj100	4	1.29	0.14	$X^2_8 = 6.66, P = 0.57$	0.54
	WaterType, HabMaj100	5	1.89	0.10	$X^2_7 = 0.82, P = 0.99$	0.56
LABO	WaterType, HabMaj100	5	0	0.18	$X^2_8 = 8.57, P = 0.43$	0.28
	RoostType, HabMaj100	5	0.37	0.15	$X^2_6 = 2.52, P = 0.87$	0.27
	WaterType, HabMaj100, HabHet100	6	0.79	0.12	$X^2_8 = 8.75, P = 0.36$	0.29
	HabMaj100	4	0.92	0.11	$X^2_7 = 13.01, P = 0.07$	0.21
	RoostType, HabMaj100, HabHet100	6	1.42	0.09	$X^2_8 = 9.06, P = 0.34$	0.27
	HabHet100, HabMaj100	5	1.78	0.07	$X^2_8 = 17.26, P = 0.03$	0.29
LASE	RoostType, HabMaj500, HabHet500	6	0	0.20	$X^2_8 = 11.26, P = 0.19$	0.68
	RoostType, HabMaj100, HabHet100	6	0.39	0.16	$X^2_7 = 4.78, P = 0.69$	0.59
	RoostType, HabMaj100	5	0.89	0.13	$X^2_6 = 2.05, P = 0.55$	0.55
	WaterType, HabMaj100, HabHet100	6	1.35	0.10	$X^2_8 = 6.56, P = 0.59$	0.56
	WaterType, HabMaj100	5	1.84	0.08	$X^2_8 = 7.12, P = 0.52$	0.52
MYAU	Roostype, HabHet100	5	0	0.25	$X^2_8 = 10.49, P = 0.23$	0.25
	WaterType, HabHet500	5	0.32	0.14	$X^2_8 = 11.73, P = 0.16$	0.28
	Roostype, HabMaj100	5	0.37	0.13	$X^2_7 = 3.67, P = 0.82$	0.23
	Roostype	4	0.52	0.12	$X^2_7 = 11.58, P = 0.12$	0.20
	Roostype, HabHet500	5	1.37	0.08	$X^2_8 = 12.82, P = 0.12$	0.20
	Roostype, HabMaj500	5	1.37	0.08	$X^2_8 = 2.12, P = 0.98$	0.20
NYHU	Roostype, HabMaj500, HabHet500	6	0	0.27	$X^2_8 = 8.05, P = 0.43$	0.65
	Roostype, HabMaj500	5	0.11	0.26	$X^2_8 = 1.36, P = 0.99$	0.62
PESU	Roostype, HabMaj100, HabHet100	6	0	0.93	$X^2_4 = 0.05, P = 0.99$	0.74

a. CORA = *Corynorhinus rafinesquii*, EPFU = *Eptesicus fuscus*, LABO = *Lasiurus borealis*, LASE = *Lasiurus seminolus*, MYAU = *Myotis austroriparius*, NYHU = *Nycticeius humeralis*, PESU = *Perimyotis subflavus* that will require additional investigation to confirm with a greater degree of precision.

The habitat type that composed the majority of the area within 100 m of the capture site was the variable with the highest relative importance weight for four species (tricolored, big brown, red, and Seminole bats) and the second highest relative importance weight for Southeastern bats; the relative importance weight was 0.17 for tricolored, 0.15 for big brown, 0.12 for red, and 0.09 for Seminole and Southeastern bats. Trends suggest that all five species were more likely to occur at capture sites dominated by upland habitats or disturbed habitats rather than wetland habitats (Table 3). The habitat type that composed the majority of the area within 500 m of the capture site was the variable with the greatest importance weight for only one species (evening bat), with a weight of 0.10. Trends suggest this species was more likely to be present at sites with upland vegetation than wetland vegetation at this larger spatial scale.

The type of anthropogenic roost structure present at the capture site was the variable with the greatest importance weight for Southeastern bats (weight of 0.09), and second highest weight for tricolored, evening, Seminole, and big brown bats (relative importance weights of 0.14, 0.10, 0.08, and 0.07 respectively). Trends suggest that evening, Seminole, and big brown bats were more likely to be present at sites with bridges but not culverts, and that Southeastern bats were more likely to be present at sites with culverts (Table 3).

The type of water body at the capture site was the variable with the highest relative importance weight for big-eared bats (weight of 0.13). Trends suggest this species was more likely to be pres-

Table 3. Model-averaged parameter estimates with standard errors and 95% confidence intervals for models derived using logistic regression in predicting probability of occurrence of bat species in and near the Apalachicola National Forest, 2012.

Bat species[a]	Habitat characteristic	Variable importance weight	Variable[b]	Parameter estimate ± SE	95% CI (lower, upper)
CORA	WaterType	0.13	Dry	10.5 ± 572.5	−1111.6, 1132.6
			Pond	−4.4 ± 44.2	−91.0, 82.2
			Swamp	4.2 ± 22.6	−40.1, 48.6
	HabMaj100m	0.06	Disturbed	6.1 ± 22.4	−37.8, 50.0
			Upland	1.5 ± 37.4	−71.9, 74.8
	HabHet100m	0.03	–	−0.3 ± 0.3	−0.9, 0.2
	HabMaj500m	0.07	Upland	0.1 ± 6.6	−12.8, 12.9
	HabHet500m	0.09	–	−0.2 ± 2.6	−5.4, 4.9
EPFU	WaterType	0.03	Dry	−4.7 ± 204.1	−404.6, 395.3
			Pond	0.3 ± 14.2	−27.6, 28.2
			Swamp	−2.5 ± 68.8	−137.5, 132.4
	RoostType	0.07	Concrete bridge	0.3 ± 1.7	−2.9, 3.6
			Other bridge	0.4 ± 315.5	−618.0, 618.9
			Culvert	−3.9 ± 315.3	−621.8, 614.0
	HabMaj100m	0.15	Disturbed	6.3 ± 11.8	−16.9, 29.5
			Upland	4.9 ± 9.3	−13.2, 23.1
	HabHet100m	0.06	–	0.0 ± 0.4	−0.7, 0.7
LABO	WaterType	0.06	Dry	−6.0 ± 285.8	−566.1, 554.2
			Pond	0.0 ± 0.7	−1.3, 1.3
			Swamp	0.0 ± 0.8	−1.5, 1.5
	RoostType	0.05	Concrete bridge	0.2 ± 0.7	−1.2, 1.7
			Other bridge	0.5 ± 1.3	−2.0, 2.9
			Culvert	0.1 ± 1.1	−2.0, 2.2
	HabMaj100m	0.12	Disturbed	1.5 ± 2.1	−2.6, 5.5
			Upland	0.9 ± 1.3	−1.7, 3.5
	HabHet100m	0.06	–	0.0 ± 0.1	−0.3, 0.3
LASE	WaterType	0.05	Dry	4.6 ± 270.5	−525.5, 534.7
			Pond	0.3 ± 0.9	−1.4, 2.0
			Swamp	−0.8 ± 1.0	−2.7, 1.2
LASE *(cont.)*	RoostType	0.08	Concrete bridge	0.6 ± 1.3	−1.9, 3.1
			Other bridge	0.8 ± 1.6	−2.4, 4.0
			Culvert	−2.5 ± 89.3	−177.6, 172.5
	HabMaj100m	0.09	Disturbed	4.3 ± 162.6	−314.4, 322.9
			Upland	2.6 ± 89.3	−172.5, 177.8
	HabHet100m	0.06	–	0.1 ± 0.3	−0.4, 0.6
	HabMaj500m	0.07	Upland	2.1 ± 2.0	−1.7, 6.0
	HabHet500m	0.05	–	−0.2 ± 0.3	−0.8, 0.4
MYAU	WaterType	0.03	Dry	−4.1 ± 191.0	−378.5, 370.4
			Pond	−0.3 ± 0.6	−1.4, 0.8
			Swamp	0.0 ± 0.5	−1.0, 1.0
	RoostType	0.09	Concrete bridge	0.0 ± 0.8	−1.5, 1.6
			Other bridge	0.5 ± 1.3	−2.1, 3.1
			Culvert	6.7 ± 256.7	−496.5, 509.8
	HabMaj100m	0.06	Disturbed	0.3 ± 1.0	−1.7, 2.3
			Upland	0.1 ± 0.7	−1.4, 1.5
	HabHet100m	0.05	–	0.0 ± 0.2	−0.3, 0.4
	HabMaj500m	0.03	Upland	0.1 ± 0.5	−0.9, 1.0
	HabHet500m	0.03	–	0.0 ± 0.1	−0.2, 0.2
NHYU	RoostType	0.10	Concrete bridge	1.7 ± 1.4	−1.1, 4.5
			Other bridge	3.0 ± 2.8	−2.4, 8.5
			Culvert	−1.0 ± 1.8	−4.6, 2.5
	HabMaj500m	0.10	Upland	2.6 ± 2.3	−1.9, 7.2
	HabHet500m	0.07	–	0.2 ± 0.3	−0.3, 0.6
PESU	RoostType	0.14	Concrete bridge	0.0 ± 22.0	−43.0, 43.1
			Other bridge	0.2 ± 244.0	−478.0, 478.4
			Culvert	0.0 ± 407.3	−798.3, 798.3
	HabMaj100m	0.17	Disturbed	0.7 ± 118.7	−232.0, 233.4
			Upland	0.5 ± 93.2	−182.3, 183.2
	HabHet100m	0.17	–	−0.1 ± 5.5	−10.8, 10.6

(continued in next column)

a. CORA = *Corynorhinus rafinesquii*, EPFU = *Eptesicus fuscus*, LABO = *Lasiurus borealis*, LASE = *Lasiurus seminolus*, MYAU = *Myotis austroriparius*, NYHU = *Nycticeius humeralis*, PESU = *Perimyotis subflavus*
b. The reference category for water type is 'creek', for roost type is 'none', and for both habmaj100m and habmaj500m is 'wetland'.

ent at sites with no water or with swamps rather than at sites with ponds or creeks (Table 3).

Diet

We analyzed 138 guano samples from eight species of bats, and identified 10 invertebrate orders therein (Tables 4, 5). Hemiptera (true bugs) was the order most frequently found in guano; this order was present in every sample investigated for three species of bats, as well as in >75% of the samples of four of the remaining five species (Table 5). Lepidoptera (moths) and Coleoptera (beetles) were the orders that occurred second and third most frequently in guano samples, respectively (Table 5). Hymenoptera (bees and wasps), Diptera (flies), Araneae (spiders), and Acari (mites) each occurred in ≥25% of samples of four to seven bat species (Table 5). Neuroptera (lace wings), Odonata (grasshoppers and crickets), and Trichoptera (caddisflies) were present but uncommon in the diets of bats.

Table 4. Mean percent volume of food items identified in fecal pellets of each species of bat in and around the Apalachicola National Forest, 2012. Sample sizes (no. samples per species) appear in parentheses. CORA = Rafinesque's big-eared bat (*Corynorhinus rafinesquii*), EPFU = big brown bat (*Eptesicus fuscus*), LABO = red bat (*Lasiurus borealis*), LASE = Seminole bat (*L. seminolus*), MYAU = Southeastern bat (*Myotis austroriparius*), NYHU = evening bat (*Nycticeius humeralis*), PESU = tricolored bat (*Perimyotis subflavus*), and TABR = Brazilian free-tailed bat (*Tadarida brasiliensis*).

	CORA (4)	EPFU (2)	LABO (21)	LASE (21)	MYAU (27)	NYHU (46)	PESU (5)	TABR (12)
Acari	1.3	2.5	1.2	0.0	0.0	1.8	1.1	0.4
Araneae	1.3	15.0	1.9	0.0	16.3	2.5	6.2	1.7
Coleoptera	7.5	70.0	26.2	22.1	10.9	19.0	26.0	4.2
Diptera	0.0	0.0	1.7	0.5	3.0	1.4	1.1	1.7
Hemiptera	1.3	7.5	51.9	66.7	23.1	50.3	33.5	32.9
Hymenoptera	1.3	2.5	3.3	5.0	2.8	15.5	5.1	1.7
Lepidoptera	73.8	2.5	12.9	5.7	36.7	8.5	23.3	56.3
Neuroptera	0.0	0.0	0.5	0.0	0.9	0.2	0.3	1.3
Odonata	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0
Trichoptera	13.8	0.0	0.5	0.0	6.1	0.3	3.4	0.0
Unknown	0.0	0.0	0.0	0.0	0.0	0.3	0.1	0.0

Table 5. Frequency of occurrence of food items identified in fecal pellets of each species of bat in and around the Apalachicola National Forest, 2012. Sample sizes (no. samples per species) appear in parentheses. CORA = Rafinesque's big-eared bat (*Corynorhinus rafinesquii*), EPFU = big brown bat (*Eptesicus fuscus*), LABO = red bat (*Lasiurus borealis*), LASE = Seminole bat (*L. seminolus*), MYAU = Southeastern bat (*Myotis austroriparius*), NYHU = evening bat (*Nycticeius humeralis*), PESU = tricolored bat (*Perimyotis subflavus*), and TABR = Brazilian free-tailed bat (*Tadarida brasiliensis*).

	CORA (4)	EPFU (2)	LABO (21)	LASE (21)	MYAU (27)	NYHU (46)	PESU (5)	TABR (12)
Acari	25	50	24	0	0	28	40	8
Araneae	25	50	29	0	81	15	60	17
Coleoptera	25	100	76	81	48	76	60	58
Diptera	0	0	19	10	41	28	80	33
Hemiptera	25	100	90	100	78	93	80	100
Hymenoptera	25	50	19	52	26	80	60	33
Lepidoptera	100	50	71	62	93	67	80	92
Neuroptera	0	0	5	0	19	4	0	25
Odonata	0	0	0	0	4	0	0	0
Trichoptera	25	0	5	0	11	2	0	0
Unknown	0	0	0	0	0	7	0	0

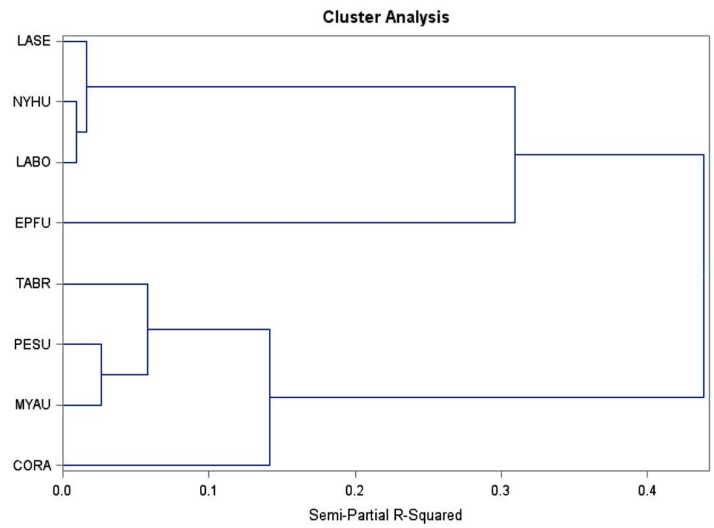

Figure 1. Dendrogram resulting from cluster analysis of diet composition of bats in and around the Apalachicola National Forest, 2012. LASE = Seminole bat (*Lasiurus seminolus*), NYHU = evening bat (*Nycticeius humeralis*), LABO = red bat (*L. borealis*), EPFU = big brown bat (*Eptesicus fuscus*), TABR = Brazilian free-tailed bat (*Tadarida brasiliensis*), PESU = tricolored bat (*Perimyotis subflavus*), MYAU = Southeastern bat (*Myotis austroriparius*), and CORA = Rafinesque's big-eared bat (*Corynorhinus rafinesquii*).

Despite the preponderance of Hemiptera in diets of nearly all individual bats, differences in diet composition were evident among bat species (Tables 4, 5). The long internodal distances in the dendrogram resulting from the cluster analysis indicate bats clustered into two broad groups based on diets (Pielou 1984; Figure 1). One group consisted of bat species whose diet was composed of a large portion of Lepidoptera (big-eared, free-tailed, Southeastern, and tricolored bats), and the other group contained species whose diet was composed of a large portion of Coleoptera (Seminole, evening, red, and big brown bats). Within these groups, evening, red, and Seminole bats exhibited the greatest degree of overlap in food habits, as evidenced by short internode distances in the dendrogram (Figure 1). The species with the most specialized diets were big-eared bats and big brown bats (Tables 4 and 5, Figure 1).

Discussion

Our intensive three-night sampling effort generated a snapshot of habitat use of eight of the nine bat species expected to occur in the region at this time of year. Note that a tenth species occurs in the region (Hoary bat, *L. cinereus*), but is believed to migrate into

Florida from more northern states between October and April, and was therefore not expected to occur during our late May surveys (Marks and Marks 2006). The northern yellow bat (*L. intermedius)* is known to occur in the region year-round but we did not capture it. Northern yellow bats are rarely encountered through mist netting efforts in large blocks of forest because they are generally associated with mature live oak trees (Menzel et al. 1999) and suburban areas where palm trees are more prevalent (Marks and Marks 2006).

Habitat Use

The best predictor of species presence for four of the seven bat species investigated statistically (tricolored, big brown, red, and Seminole bats) was predominant vegetation community within a 100-m radius of the capture site. This was also the second best predictor for Southeastern bats. In other words, these bat species were more responsive to the predominant vegetation community at a small spatial scale than to the type of anthropogenic roost structure, the type of water body, the predominant vegetation community at a larger spatial scale, or the heterogeneity of the vegetation community at either small or large spatial scales. The primacy of stand-scale features over landscape-scale features has previously been demonstrated for roost site selection for many bat species in the Southeast (Elmore et al. 2004, Ford et al. 2006, Loeb and O'Keefe 2006, Perry et al. 2008), but few studies have investigated this issue as it pertains to foraging habitat selection. Furthermore, although bat use of water features is well-known, the trend we observed for greater probability of occurrence of these five bat species at water features located in predominantly upland or disturbed vegetative communities rather than wetland communities at the small spatial scale suggests that special consideration ought to be given to potential effects on bats when planning management activities which influence vegetation surrounding water features in upland or disturbed habitats. According to Florida's silvicultural Best Management Practices (BMPs), little precaution is recommended when harvesting trees near small or intermittent water bodies (Karels 2008). Current BMPs simply recommend no clearcut harvesting within 35' of streams <20' wide, 75' of streams 20–40' wide, or 200' of streams >40' wide. Our results suggest vegetation composition within 100 m (328') of small and intermittent water bodies is relevant to numerous species of bats, so current BMPs may not be adequate to protect foraging habitat of these species near water bodies.

For five species of bat investigated (big brown, Seminole, evening, tricolored, and Southeastern), the type of anthropogenic roost structure present at a site was a better predictor of species occurrence than the type of water body present. This suggests that careful consideration ought to be given when decisions are made regarding the renovation, replacement, or addition of bridges and culverts, as these man-made features can have a relatively strong influence on bat occurrence patterns. These structures have the capacity to provide roosting habitat for a variety of Southeastern bat species (Menzel et al. 2003, Gore 2005), with the physiological health of individuals roosting in bridges potentially higher than that of individuals roosting in natural structures (Allen et al. 2010). We found that probability of occurrence among sites with different types of roost structures varied among species, which is in congruence with previous research demonstrating that preferences for specific bridge design features varies among bat species (Keeley and Tuttle 1999, Gore 2005). It is worth noting that one of the five species for which the type of anthropogenic roost structure received fairly high weighting (*Lasiurus seminolus*) is not known to use such structures for roosting, but was perhaps more likely to be found at sites with particular types of roost structures because of the size of waterways they are associated with. This large species of bat tends to forage over water and in open areas, so was likely found in areas with structures typically associated with these structures (bridges as opposed to culverts).

Diet

In general, diets of bats in our brief study were similar to those reported for the same species in studies of longer duration in other locations throughout the southeastern United States. Studies from South Carolina, Georgia, and Florida have reported that the diet of big brown bats regularly consists of a large proportion of Coleoptera; that evening bat diets contain large portions of Coleoptera, Hemiptera, and Hymenoptera; that red bat diets consist primarily of Coleoptera, Hemiptera, and Lepidoptera; that tricolored bats feed mostly on Hemiptera, Coleoptera, and Lepidoptera; and that big-eared bats consume predominantly Lepidoptera (Carter et al. 1997, 2004; Menzel et al. 2002; Whitaker and Barnard 2005; Whitaker et al. 2007).

However, the diets of Seminole and Brazilian free-tailed bats in the present study were somewhat different than those in other regions at other times. Diets of Seminole bats in Georgia and South Carolina reportedly include fairly large portions of Hymenoptera along with large portions of Coleoptera and Lepidoptera, with Hemiptera typically ranking as third or fourth in total volume (Carter et al.1997, 2004). In contrast, we found this species' diet to be predominantly Hemiptera and Coleoptera, with quite small proportions of Lepidoptera and Hymenoptera. Also, although we could find no published reports of the diet composition of Brazilian free-tailed bats from states neighboring Florida, this species' diet is known to consist of a large portion of Lepidoptera and

Coleoptera in Texas (Kunz et al. 1995, Lee and McCracken 2005), whereas we found this species to consume primarily Lepidoptera and Hemiptera. We consider the large portion of Hemiptera consumed across all bat species in our study to be a noteworthy issue. However, given the short duration of our data collection period, it may simply have been the case that Hemiptera were unusually abundant relative to other orders of invertebrates during our brief investigation. One additional difference between diet patterns observed in the present study versus most other published reports is that spiders were present in the diets of all bat species but one, and they composed a substantial volume of diets of Southeastern bats. Because spiders are flightless, their presence in bat diets suggests that bats may be consuming spiders that are ballooning or suspended in open areas (Best et al. 1997, Schulz 2000), or bats are gleaning.

Species Groups

For volant taxa such as bats, partitioning of resources can occur over space (horizontal or vertical) or time (within nights or among nights). By examining short-term patterns of habitat use, diet composition, within-night timing of peak activity, and also considering what is known about foraging height preferences, we can posit how species within a community are partitioning or sharing resources. This can conceivably assist in identification of species groups that could be managed collectively to reduce the burden of managing for each species individually.

Our diet analyses revealed two distinct assemblages of species. Coleoptera was the second most abundant order in diets of species in one of these groups (big brown, evening, red, and Seminole bats). These four species are known to use overlapping foraging spaces: evening bats and big brown bats forage close to the canopy, and red and Seminole bats forage just above the canopy (Jennings 1958, Zinn 1977). The peak time of capture of three of these four species was also quite similar: mean capture time was 1 hour 26 minutes after sunset for red bats, 1 hour 31 minutes after sunset for Seminole bats, 1 hour 39 minutes after sunset for evening bats, and 2 hours 29 minutes after sunset for big brown bats. Thus, there appears to be fairly limited partitioning of resources among these species. To simplify management decisions in the large blocks of conifer-dominated forests we investigated, these four species could be considered a single guild of beetle-eating bats that forage primarily near the canopy in waterways embedded in upland and disturbed vegetative communities.

Lepidoptera was the second most abundant order in the diets of species in the other group (Brazilian free-tailed, big-eared, Southeastern, and tricolored bats). These four species are known to use different foraging spaces: Brazilian free-tailed bats forage at high altitudes, big-eared and tricolored bats forage under the canopy, and Southeastern bats forage low over water (Jennings 1958, Zinn 1977). We also found differences in the peak time of capture (mean capture time for tricolored and Southeastern bats was 2 hours 4 minutes after sunset, for Brazilian free-tailed bats was 2 hours 23 minutes after sunset, and for big-eared bats was 2 hours 51 minutes after sunset). Different factors were most influential to occurrence patterns of each of these four species (Table 3). Thus, these species are partitioning resources through horizontal space, through vertical space, and perhaps by foraging at slightly different times of night. From a management perspective, there is little reason to consider these moth-eating species as a single guild that could be managed cohesively.

Management Implications

We were unable to neatly partition bats into groups based on habitat use and diet, which may have eased the burden of managers tasked with developing management plans at the individual species level. However, the best supported models for four species predicted bat occurrence from nearby habitat, with bat occurrence most strongly tied to the presence of upland or disturbed vegetative communities within close proximity (100 m). Thus, consideration ought to be given to potential effects on bats when planning forest management activities which influence areas adjacent to creeks, ponds, and swamps in upland and disturbed habitats. Because silvicultural Best Management Practices in Florida are fairly liberal around intermittent water bodies (Karels 2008), additional research on bat use of stringers (trees left on or near the bank along both sides of intermittent streams, intermittent lakes, and sinkholes with intermittent water for the purpose of providing habitat for wildlife during tree harvesting) is needed so that recommendations for avoiding habitat degradation for bats in streamside management areas can be crafted. Also, careful consideration should be given to the design of water crossing structures. Bat species differ in their preferences for man-made roost structures, so no one bridge or culvert design will provide quality habitat for all species in a local bat community. Since seasonal timing of bridge use by bats varies greatly (Trousdale and Beckett 2004, Ormsbee et al. 2007), care should be taken when deciding the time of year such structures are disturbed for the purpose of renovation or replacement.

Suggestions for Future Bat Blitz Efforts

The primary function of historical bat blitzes has been to provide an enjoyable and efficient means for expert bat biologists to create an inventory of bat species in areas where local knowledge and expertise is limited, while also educating the local public. Our analyses suggest that data collected through traditional means have limited power when used to evaluate habitat use. We believe that with a few small changes, these brief surveys have the potential to also contribute foundational data on local bat habitat use and diet which could be informative to forest management practices. We recommend that careful attention be given to deciding what type of data collection techniques would provide the most useful data during future events.

Bat Blitzes have historically used bat captures (mist netting at a suite of sites one evening per site) over the course of a few consecutive nights to obtain lists of species present in the region. The ability to use data from such short duration events to make inference to habitat use may be fairly limited for a number of reasons. First, when surveys involve only one visit per site, it is not possible to obtain reliable estimates of detection probabilities to model occupancy (MacKenzie and Royle 2003). Due to the short nature of such events, this drawback cannot be overcome simply by netting each site more than one night; bats often avoid areas where they have been captured on subsequent nights (Kunz and Brock 1975). Furthermore, mist netting has many limitations when used as a means to evaluate habitat use, including differential capture probability among sites, among species, or among nets set by different biologists (Hayes et al. 2009). A more reliable snapshot of habitat use could be obtained through acoustic surveys. Conceivably participants at future Bat Blitzes could be solicited to bring acoustic detection devices to use during the event; these units could be calibrated and then deployed at numerous sites for several nights to obtain more precise insight into patterns of local bat habitat use. Also, data on bat diets has not been consistently collected at all Bat Blitz events, but given the small burden required to collect such data, this could easily become standard practice. A combination of direct capture, acoustic surveys, and guano collection could provide more insight into local bat activity and habitat use than the historical emphasis on capture only.

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